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Electronic Computer Research

The National Bureau of Standards program in electronic computers includes research and development in machine design, applications and programing methods, and technical advisory and problem-solving services. This issue of the Technical News Bulletin presents a number of recent developments resulting from work in these areas.

INITIATED during the early postwar years, the computer program originated in requests from several Government agencies for assistance in evaluating the potential application of automatic electronic digital computers to their problems, and in procuring suitable installations. Studies conducted to establish design specifications eventually led to a program for the development of improved computer components and circuitry, and subsequently to the design and construction of SEAC, the National Bureau of Standards Electronic Automatic Computer. Dedicated in June 1950, this machine was the first superspeed automatically sequenced electronic digital computer to go into productive operation for the Government. At the same time, another computer, SWAC, was built in an effort to utilize the most advanced techniques then available; it became the first computer to operate solely with an electrostatic memory.

Today the Bureau's computer activities provide the Government with a comprehensive and readily available information center in the new and rapidly growing field of high-speed electronic computers. An increasing number of requests are being received from Federal agencies for the solution of computer problems in science, engineering, management, and operation, and for advisory services in computational methods and in such areas as massive paperwork operations, control systems, and simulation. These advisory activities strengthen the Bureau's basic computer program, which ranges from research in components, circuits, and systems, to advanced mathematical work in numerical analysis, programing methods, and computer applications.

SEAC has proved to be one of the most useful facilities for evaluating new computer components and techniques. By June 1957 the installation had logged approximately 24,000 hr of useful time devoted primarily to scientific problems for the Bureau and other Government agencies. At this time a much more advanced commercial computing facility was leased, SEAC's function was reoriented to support development activities of the data processing systems laboratory, and SEAC was converted to a research tool as described on p. 65 of this issue. SWAC has been turned over to the University of California, where it is still in successful operation.

Current studies of advanced components and techniques include exhaustive investigations of transistors, magnetic cores, magnetic films, and ferroelectric elements and their applications. This work is providing information basic to the design and development of new and improved digital circuitry, as typified by the pulse-repeater packages described on pages 63, 77, and 78.

Closely related to these studies is research on the logical design of more advanced, higher-speed units for information processing and control systems (see "A High-Speed Multiplier", p. 58). Results of such research are incorporated into system organizations that utilize the new digital-circuitry developments.

Another area of effort combines the older analog-computer technology with both the logical and engineering aspects of digital data processing. Experiments involving the simulation of proposed designs of aircraft controls and jet engines are now being evaluated. Studies of the application of combined analog-digital techniques to real-time data processing are also in process. One of these studies, reported on p. 68, has culminated in the development of a prototype facility to simulate complex man-machine environments.

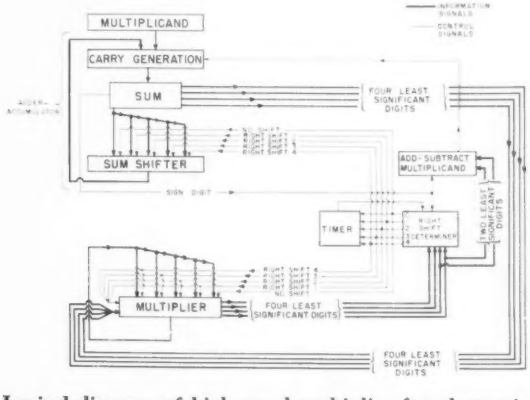
Complementing these activities are analytical studies that seek to apply the potential of engineering developments to massive information-handling problems. The large-scale record keeping and management operations of government, such as those encountered in accounting, data editing, information files, information retrieval, and logistics planning, require detailed analyses that have resulted in the formulation of performance requirements for both data-processing equipment and methods. When available equipment cannot meet these requirements, further laboratory development is undertaken.

The Bureau's current efforts toward pilot mechanization of the search procedure of the United States Patent Office (p. 75) exemplify such applications engineering. Allied studies include investigation of methods for characterizing such information as text, pictures, drawings, and graphs in forms that machines can process efficiently (p. 60); theoretical studies of information storage and retrieval; and development of mechanical-translation techniques.

A High-Speed Multiplier for electronic digital computers

CONTINUED RESEARCH at the Bureau on the logical design of electronic digital computers has resulted in an improved method of multiplying.[1] Speed increases up to threefold can be achieved by omitting some of the unnecessary time-consuming steps that are ordinarily included when multiplication is done by a simple sequence of repeated additions. Developed by J. L. Smith and A. Weinberger of the data processing systems laboratory, the technique can be generally applied and does not require any particular kind of digital computing components or circuitry.

In attacking the general problem of increasing electronic computer speed, the Bureau has followed two distinct approaches. One approach has been to develop electronic components and circuitry that can amplify, store, and switch signals at higher basic repetition rates.



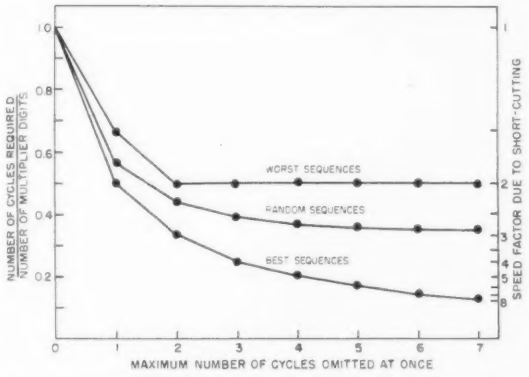
Logical diagram of high-speed multiplier for electronic digital computers.

The other approach has been to increase over-all speed by organizing slower electronic elements into more efficient systems as in the improved multiplier. An obvious example of the second method is the organizing of the basic elements so that several separate steps of an operation can be carried out simultaneously by several identical units of the same machine. A straightforward application of this principle, however, often entails the use of excessively large amounts of equipment. As a rule, therefore, methods based on the use of duplicated equipment are less desirable than the use of (1) more ingenious mathematical computing methods and (2) logical processing methods specially adapted to the physical peculiarities of the available computing components. In terms of equipment needs, the present improved multiplier compares favorably with other proposed methods that require several adding devices.

The most common method of multiplying with binary digital computers is the repeated addition of the multiplicand. (In a binary system, only ones and zeros are used.) A one-position shift accompanies each addition and a running sum of the partial products is maintained in an accumulator. In this process, the accumulator is cleared initially. During the first addition cycle, if the least significant digit of the multiplier is a one, the multiplicand is added to the contents of the accumulator. If it is a zero, nothing is added. In either case, the contents of the accumulator and of the multiplier register are shifted one position to the right. Similarly, during the second addition cycle, the next more significant digit of the multiplier determines whether the multiplicand is or is not added to the contents of the multiplier. Again, in either case, the contents of the accumulator and of the multiplier register are shifted

one position to the right. After each multiplier digit in turn has controlled the addition of the multiplicand to the contents of the accumulator (with the one-position shift for each cycle) the multiplication operation is complete, and the final product is available in the accumulator.

The Bureau's multiplication system takes advantage of the fact that some of the steps described above can be omitted when a sequence of several consecutive ones or zeros appears in the multiplier. Whenever any multiplier digit is a zero and nothing is to be added to the partial-product sum, it is obvious that the addition cycle could be omitted entirely, and that only a shift need be performed. A sequence of zeros would allow omitting as many addition cycles as there are zeros. Similarly, if a sequence of ones occurs in the multiplier, cycles corresponding to these ones may also be omitted in



Graph showing how computation speed is improved when using the high-speed multiplication technique.

much the same way, if subtraction of the multiplicand from the partial-product sum is provided for.

Consider a string of n consecutive ones in the multiplier. The numerical value of just this string of binary ones is

$$2^{n-1}+2^{n-2}+2^{n-3}+\ \ldots\ +2^1+2^0$$

and is equivalent to 2^n-2^0. Therefore, in computing the partial products corresponding to this string of n ones, one subtraction of the multiplicand for the right-hand one, and one addition of the multiplicand for the zero to the left of the string of ones are sufficient.

A fundamental requirement of the multiplication process is that the contents of the accumulator (and of the multiplier register) be shifted one position to the right for each digit of the multiplier, regardless of whether or not any of the cycles are omitted. Therefore, in order that the multiplication time be shortened to the fullest extent by omitting cycles of the operation, some arrangement must be made for accomplishing multiple-position shifts as rapidly as possible. Ideally, the shifts that correspond to cycles to be omitted should be combined with the shift that accompanies the last cycle actually performed. Thus, for example, if three cycles are to be omitted, one shift of four digit positions should be executed instead of four shifts of one position each.

Considerations of the logical gating required to accomplish any shift make it evident that the number of shift paths must be very limited. Also, there is a point of diminishing returns, which eliminates the need to provide more shift paths than are required to omit either none, one, two, or three cycles at any one time.

Two important features must be incorporated into this method of multiplication. First, shift paths of the same length provided for the accumulator must also be provided for the multiplier register in order to have the proper multiplier digits at hand for controlling the next cycle. Second, provision must be made for examining a number of succeeding multiplier digits at once to determine how many of the succeeding cycles are to be omitted, and whether the multiplicand should be added or subtracted (or neither) during the current cycle.

Mathematical analysis of several different kinds of digital sequences has helped to give some measure of the effectiveness of this shortcut multiplication technique. The upper limit of effectiveness is attained with strings of similar digits whose lengths are multiples of $n+1$, where n is the maximum number of cycles that can be omitted at once. For $n=3$, as used in the Bureau's system, the number of cycles required is only one-fourth of the number of multiplier digits. There are many such best sequences, and they would be likely to occur rather often in practice.

The lower limit of effectiveness can be determined by finding repetitive sequences of multiplier digits such that the least number of digits can be omitted. In this worst case, for n greater than 1, the number of cycles actually required is one-half of the total number of digits in the multiplier. It is unlikely that such sequences (of which there are many possible) would occur very often in practice, although they do occur in the binary representation of such decimal fractions as $\frac{1}{3}$, $\frac{1}{5}$, $\frac{1}{9}$, $\frac{1}{10}$, etc.

From the practical standpoint, perhaps the most meaningful determination of effectiveness is that based on a purely random sequence of multiplier digits. In this case, it turns out that the number of cycles for $n=3$ is about 40 percent of the number of digits. In practice, multiplier digits are often not random, nor even apparently so, but experience indicates that departures from randomness usually favor sequences of similiar digits. Thus, the average number of cycles required for multiplications will generally be less than the theoretical number for random sequences. If a curve were plotted for the average number of cycles required for multiplier sequences usually occurring in practice—a mixture of random digits and strings of similar digits—this curve would lie between the curve for purely random sequences and the curve for the best sequences.

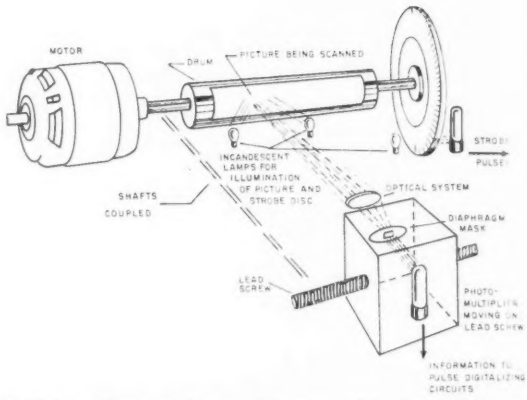
[1] *For further technical information see* System design of digital computers at the National Bureau of Standards: methods for high-speed addition and multiplication. *NBS Circular 591, section 1, price 20¢. Available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.*

Processing Pictorial Information on Digital Computers

EXPLORATORY EXPERIMENTS in manipulating the information content of pictures [1] have recently been carried out on SEAC, the National Bureau of Standards Electronic Automatic Computer. With the aid of appropriate scanning and display equipment, the computer converts pictures into digital form suitable for input, processes the information according to some prearranged routine, and displays the results as a visual output. Experiments are being carried out under the leadership of R. A. Kirsch of the data processing systems laboratory to increase knowledge in the possible applications of high-speed electronic computers for picture processing.

The greatest impetus for the development of automatic data-processing techniques has been the need to process at high-speed alphabetical or numerical information. Ordinarily, such information exists already in digital form. If not, it can be translated into digits. In either case, it can be assembled manually to be fed into computers with suitable input devices. Because scientists have been concentrating on the processing of conventional data, little attention has been given to the use of general-purpose computers in conjunction with special-purpose input devices for gathering unconventional types of data. In particular, there has been a lack of investigation into the use of digital computers for automatically gathering and processing information that naturally occurs in the form of pictures, diagrams, or other graphical configurations designed for visual use by human beings. Although considerable effort has been directed to such problems as recognition of printed alphabetical and numerical characters, this effort has been concerned mostly with the construction of specialized equipment for performing very specific functions. To provide more general information, the Bureau initiated a series of exploratory experiments involving the use of general-purpose digital computers to help understand the nature of pictorial information.

Processing pictorial information on a digital computer. Operator is feeding information into the computer via the scanning mechanism in the foreground.



Drawing of the device used to scan pictures. Information fed to the computer is binary zero or one depending on brightness of unit 0.25 mm square on the picture.

Equipment for Input and Output

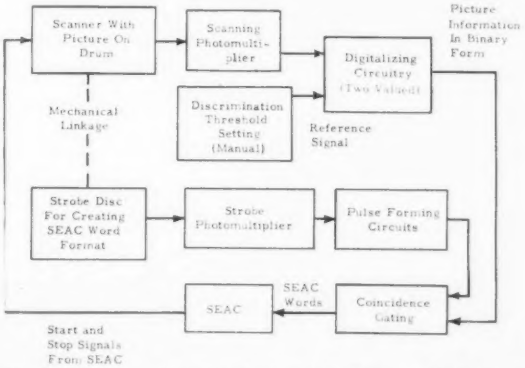
In order to feed pictorial information into SEAC, a simple mechanical drum-scanning device is used to digitalize the information in a picture. The photograph to be scanned is mounted on a drum approximately two-thirds inch in diameter. As the drum rotates, a photomultiplier and a source of illumination mounted on a lead screw move parallel to the axis of the drum. The pitch of the lead screw is such that the photomultiplier moves 0.25 mm for each revolution of the drum. A mask in the optical system illuminates a 0.25-mm square, and a strobe disk produces optical pulses each 0.25 mm of drum rotation. Thus, the photomultiplier can examine the relative reflectance of each 0.25-mm square. Through the electronic circuitry of the scanner, a dark square on the picture is converted into a binary one. A sufficiently white square produces a binary zero. The entire picture is scanned in 25 sec or less. Since the picture is 44 by 44 mm, it is converted into 30,976 binary digits, occupying 704 words of SEAC's memory.

To display a picture that has been fed into the computer from the scanner, a program was prepared to derive a pair of coordinate numbers for the position of each binary one in the picture stored in the memory. When decoded, the numbers produce a pair of analog voltages that are applied to the vertical and horizontal inputs of an oscilloscope, thus generating a visual display.

Processing Pictures on SEAC

In pattern recognition, the aim is to reduce the amount of information to the minimum necessary for recognizing one pattern from a group of patterns. In these experiments the approach was to develop a library of computational processes for simplifying patterns in order to obtain their most significant features. Preliminary experiments were concerned with determining those manipulations which would prove to be the most informative. The compilation of discrete routines for the performance of these elementary manipulations would provide the basis of a flexible system for simulating many widely diversified pattern identification logics. After determining the intended course of his pattern analysis, the programer needs only to refer to this file and to select those routines which in combination will best serve his purpose.

Furthermore, it is possible for the analyst to sit at the computer console and to draw from this tape library



Block diagram of pictorial scanning device and its associated circuitry.

several routines which he can select pragmatically after studying the results of any preceding operations, and thus guide the computer step by step toward recognition of the pattern being studied. Two forms of output can be distinguished in these routines—numerical data and transformed pictures. Numerical data can be read directly from the computer, but pictorial information must be converted before it can be displayed by the picture output scope. The picture display routine is used in such cases.

One of the simplest routines in the library counts the total black area in a pattern. This program examines each bit in sequence and tallies when the bit represents a black area. Advantage is taken of the fact that in many patterns there will be numerous words that are all black or all white. By comparing whole words against constants of all zeros or all ones, much time is saved. The area counting process requires approximately 30 sec on SEAC.

A routine was designed to count the number of objects in a picture. A black area is defined to be an "object" when it is completely surrounded by white areas. When a photograph containing 53 objects was fed into SEAC, the computer produced the correct count. Although some of the objects might be intuitively interpreted as two or more overlapping objects, this intuitive definition of an object was not used.

The routine for counting objects was not limited to counting solid, simply connected objects. When a picture of nine abstract shapes was fed into SEAC, it produced the correct count even though the objects contained re-entrant profiles (i. e., a spiral) or were multiply-connected (a letter B) or were interspersed among other objects. Another type of question that SEAC was programed to answer involved evaluating the area of each of the objects counted. The area of an object was defined as the total black part of the object and did not include, for example, the white circle enclosed by a black annular area.

By combining the object-counting routine with the area-counting routine, it became possible to feed a picture into the scanner on SEAC to determine the number of objects having areas greater than a certain value. This eliminated specks of dirt from consideration. By a trivial modification of the program, objects could have been counted and put into classes according to their areas.

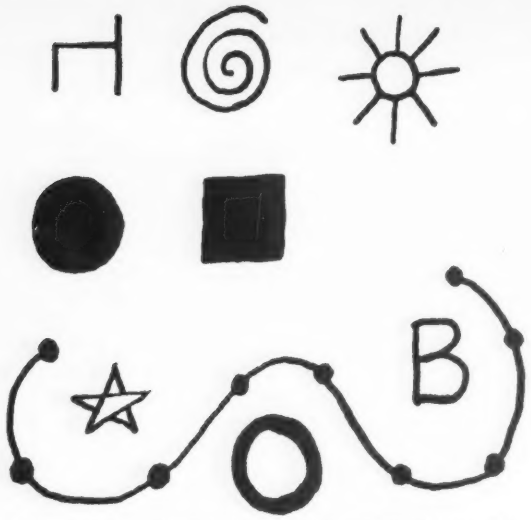
Simulating Complex Processes on SEAC

One of the most powerful features of a general-purpose computer with a picture input and output facility is the ability to study the performance of picture-processing mechanisms by simulating their behavior with a computer program. In this way, mechanisms can be "tested" in some cases under conditions that would be difficult to create under laboratory conditions.

Automatic character-sensing (print reading) machines constitute a particularly important class of picture-processing devices. A study was undertaken of various logical schemes that have been proposed for the recognition of printed characters. A routine was written to study a character-recognition logic based upon the identification of unique areas for each character in an alphabet. Under such a logical procedure for recognizing printed characters, there are certain parts of each character which are black for that character and not for any other character. These unique areas serve to identify the characters.

The routine that was proposed for SEAC to study this recognition logic compared several photographs of different characters and determined which parts of the viewing matrix were (1) black for all letters concerned, (2) white for all letters concerned, or (3) sometimes black and sometimes white. This last area is the only part of the whole viewing frame that can be used to identify characters. Studies can now be made of characters in different fonts to determine the percentage of useful recognition areas that characterize the different fonts.

One shortcoming in this routine is the fact that it produces results that are very sensitive to rectilinear translations of the characters being analyzed. To overcome this difficulty, a SEAC program was prepared that calculates the center of gravity of any picture and then shifts the picture so as to move the center of gravity to any desired place in the matrix—usually the center.



A computer routine was devised for counting the number of abstract shapes shown in the above drawing. A second routine was prepared to determine the area of each shape. The chart at right shows the results.

Object	No.	Area (0.25 mm squares)
	1	56
	2	163
	3	142
	4	187
	5	206
	6	82
	7	404
	8	142
B	9	80

The overlapping areas routine is being used to study characters that have been oriented with the shifting routine.

Effects of Simple Operations on Pictures

Programs were coded for SEAC to perform simple operations on each of the spots in a 30,000-spot picture. In each of these operations, only the immediate neighborhood of a spot was considered by the computer in determining how to operate on that spot. Simple routines of this type can readily be mechanized in the form of equipment, so experiments were performed to see whether such simple operations could produce important over-all effects on a picture.

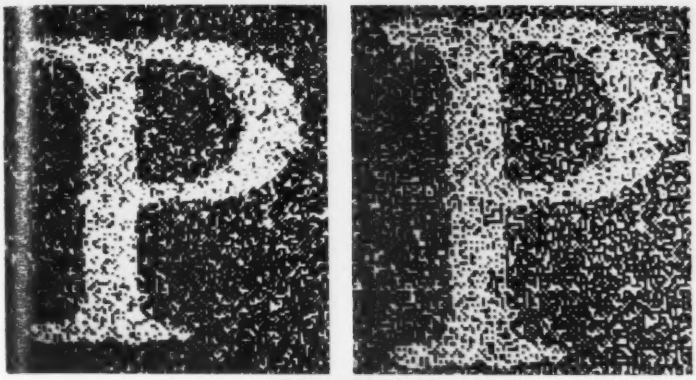
The first routine was one to add noise to a picture. It was coded so that random binary digits could be used to replace any spot in the picture. Another random number-generating routine was used to determine which spots would be disturbed by the noise. The ability of the computer to simulate any desired type of noise distribution and to produce corresponding photographs enables quite elaborate studies to be made of the effects of noise upon ease of recognizing photographic information.

Another simple operation on pictures that produced unusual results was a kind of spacial differentiation. In this operation the computer investigates every black spot. If it is completely surrounded by eight other black spots, then it is converted to a white spot. In any other case, a black spot is written. The effect of such an operation is to preserve the boundaries of an image while erasing all the internal area. After doing this operation the computer inverts all the digits of the picture, that is, it converts black to white and vice versa. This constitutes one so-called "custer" of a picture. Even after custering 50 times, some traces of the image still remain. Additional trials show also that noisy figures seem to be stable under the custering operation.

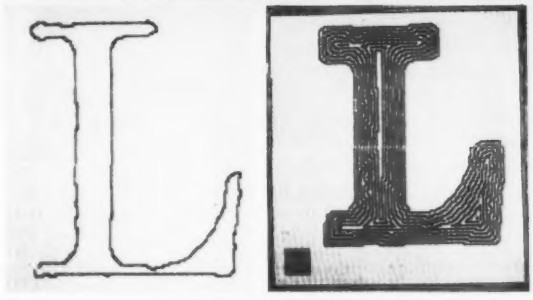
Other Picture-Processing Routines

In addition to these routines, some other simple routines have been written. These include routines to superimpose pictures, to smear pictures by translating and superimposing them, to magnify pictures so as to make their fine detail visible, to record pictures in permanent form on tapes and wire, and a routine to analyze a set of pictures to determine the number of spots that are always black or always white in the set of pictures.

These experimental picture-processing routines serve mainly to illustrate the variety of picture-processing procedures that can be performed on a general purpose facility like SEAC with its picture input and output. In addition to these experimental investigations, studies have been made of the feasibility of programing SEAC to demonstrate some picture-processing operations of considerable practical importance. In each of the following cases these studies have shown that SEAC could be programed to do the operation described, although none of the programs has actually been written.



The typewritten letter "P" (left), with random digits superimposed upon it, was "custered" 8 times (right). Note that practically no changes occurred.



These photographs demonstrate the changes in the typewritten letter "L" when subjected to the "custering" process a number of times. Essentially this process preserves the boundaries of an image while erasing the internal area. Note how speck of dirt in lower left corner apparently grows as picture is "custered" many times.

Automatic coding of chemical and electrical diagrams. For purposes of storage of information, pictorial representation of diagrams is very inefficient. For example, in a picture of the size used as SEAC input one could represent a simple transistor oscillator schematic, or a structure diagram for the chemical compound phenol. But the useful information in each of these cases is no more than about 100 or 200 bits (binary digits), whereas 30,000 bits are needed in the picture. Thus a machine procedure to accept a photograph and produce a coded output for storage by a computer would result, in this case, in a storage capacity requirement of less than one-half percent of that needed for storing the picture.

Simulation of logical procedures for recognition of of printed characters. If the more complex recognition schemes were programed and analyzed, the result might be a saving in equipment construction costs since a simulated test might lead to radical changes in a piece of proposed equipment.

Photogrammetric analysis of stereographic photographs. The intended purpose here is to produce contour maps from photographic information. There is reason to believe that it may even be possible to do photo interpretation by machine. This would require that a program be prepared to recognize and classify objects in an aerial photograph in order to superimpose cultural information on a map or to provide various other types of overlays. Some of the problems encountered here border upon the subject that has come to be known as "pattern recognition", and further research is still needed in this area.

[1] *For further technical information, see* Experiments in processing, pictorial information with a digital computer, *by R. A. Kirsch, L. Cahn, L. C. Ray, and G. H. Urban, Proceedings of the Eastern Joint Computer Conference (IRE–AIEE–ACM) 1957.*

Low-Power Plug-In Packages for electronic computer circuitry

IMPROVED ELECTRONIC COMPUTER PACKAGES have been developed at the Bureau. Although these packages perform all the logical functions of those previously developed,[1] they require far less power and thus require less cooling. By the proper interconnection of a sufficient number of such packages, most of the complex circuitry of large digital electronic computers can be constructed. Two types of packages, one containing pulse-repeater circuitry and the other containing delay lines, were developed for the Air Force Cambridge Research Center by R. H. Cahn, R. A. Toense, and S. Greenwald of the Bureau's data processing systems laboratory.

A distinctive feature of National Bureau of Standards computer design is the general similarity of most of the circuit stages. Although many hundreds of stages are required, a single basic tube circuit or pulse repeater, with minor modifications, is adaptable to the majority of requirements. Thus, the same basic circuit, when combined with delay lines as needed, can serve as a low-impedance pulse driver, as a flip-flop, and for a number of gating functions. This general circuit uniformity invites the use of mass-produced packages.

Tube Package

The tube package contains a tube, a pulse transformer, five and-gates, an or-gate for feeding the output of the gates to the grid of the tube, and an output or-gate

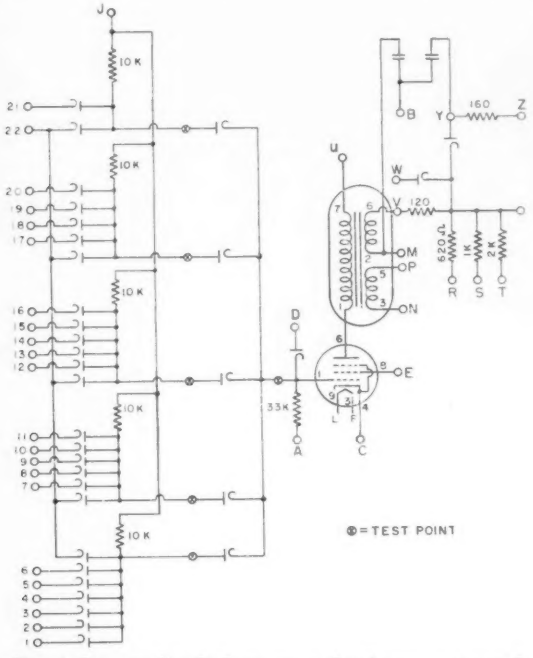
to permit the transformer to drive the gates of subsequent packages. Not all of the components are connected together in their normal operating configurations inside the package. Instead, leads are brought out to the plug, and the connections are wired into the socket. This procedure facilitates testing of suspected faulty components and also provides a wider variety of possible component combinations.

The tube is the type 404A, a high-transconductance pentode. The transformer consists of a ferrite, two-piece cup core with a 60-turn primary and two 5-turn secondaries. Two types of diodes are used in the packages: One type on the grid side of the tube, where low capacitance and low-voltage drop for low currents are of greatest importance; a second type at the output of the transformer, where a low-voltage drop for high currents is of primary importance. A number of deposited carbon resistors are used, the largest of which are only 0.25 watt. Two capacitors are included to bypass two critical voltage levels.

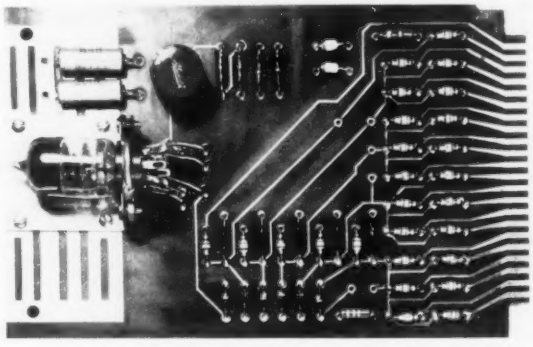
One of the five and-gates is used only for regeneration—to shape and to set the duration of the pulse. Of the other four and-gates, one has provision for four inputs, two for five inputs, and one for six inputs. In addition there is a clock input to each gate to govern pulse timing. All and-gates are connected to the grid at all times; if a gate is not used, −1.8 volts must be connected to one of its inputs to prevent it from operating. There is no provision for additional inputs to and-gates. A study indicated that the few cases where a greater number would be needed did not warrant their inclusion. Furthermore, the additional inputs would increase the capacitance of the gate and the number of pins required for the connector.

One of the transformer secondaries is always connected to provide a positive output pulse, since it is required for regeneration. A direct output from this secondary is provided, as well as an indirect output separated from the transformer by a buffer or-gate. The indirect output of the package is sent to and-gates of other tube packages. The direct output goes through either a delay line or a logical or-gate before the input and-gate of the next tube package. The other secondary can be left unconnected, although it normally is connected to provide a negative or inhibit output pulse whenever required.

The loading of the package is expressed in terms of the equivalent number of gates which a tube can drive. The unit load is an or-gate that is driven directly from the positive output of a transformer, and in turn drives a single and-gate. The maximum resistive load which a tube package can drive is 34 gates in addition to the regeneration gate. The number of gates in other packages that can be driven from only the indirect output is determined by the load resistors connected into the circuit. At least one must always be connected to provide regeneration. When all three resistors normally contained in a package are in the circuit, 20 gates can be driven from this output.



Circuit diagram for the low-power plug-in computer package. By the proper interconnection of a sufficient number of these tube packages, most of the complex circuitry of large digital computers can be constructed.

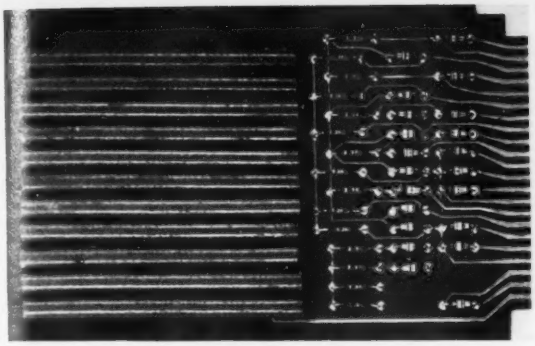


Component side of tube package. Package contains tube, transformer, bypass condensers, and a number of diodes and resistors for gating networks.

Delay-Line Package

The delay-line package contains 11 sections of delay line, some of which are permanently connected together. It also contains a number of delay-line terminations consisting of resistor-diode networks. Two of these terminations are for negative pulses and five for positive pulses. Each termination is made up of an input section, connected to the direct transformer output of a previous stage, and an output section, connected to the and-gate input of the next package. Some of the positive terminations are combined with or-gates and others are permanently connected to delay-line sections to make best use of the available number of pins on the connector.

Since the positive output termination includes some



Component side of delay line package. Package contains 11 delay line sections, and diodes and resistors to provide terminations for the delay lines.

of the same components that an or-gate requires, it is easy to add an extra or-gate input to a termination to make it either an or-gate or a termination, or both. One of the positive output terminations has three of these diodes permanently connected in, and another one has two. One of the positive input terminations has an extra diode added to form a logical or-gate that can be used when two signals are to go to the same or-gate and receive the same delay.

Mounting

The tube and delay-line packages are mounted on 4½- by 7-in. printed-circuit boards designed to plug into conventional 44-pin printed-circuit connectors. The center-to-center spacing of adjacent packages when mounted in a rack is 1⅛ in. to accommodate the type 404A tube. The printed-circuit boards are 1/16-in. epoxy glass double-clad with 0.0027-in. copper foil. Printed circuitry on both sides of the board is necessary to effect the complex wiring of the computer package without recourse either to two separate boards with two plugs or to a much wider package that would also need two plugs. Since the boards are not reinforced, the stronger epoxy glass material serves better than the more flexible XXXP material. Guide slots the full length of the package are included to minimize stress on the board and the connector during insertion and removal. A simple tool that hooks into two holes at the end of the board facilitates removal of this package.

Since all components are mounted on one side of the board, dip-soldering is appropriate only on the other side. If the component side is to be soldered, it must be done by hand. To avoid the necessity of soldering both sides, eyelets for making connections from one side of the board to the other are not used in the packages. Instead, all component mounting holes are plated through. Several test points are provided on the board to facilitate complete individual component checking after mounting. These points are also plated-through holes into which small test pins can easily be inserted.

In the tube package, the major power-dissipating components (the tube and larger resistors) are located away from the germanium diodes. The small flow of air necessary to cool the package first passes over the diodes before it reaches the tube, thus minimizing diode heating. Tests show that adequate cooling of the glass bulb can be accomplished without a metal shield. Using a barely detectable flow of air and with the tube operating at maximum power dissipation, the temperature of the bulb can be maintained at 62° C, whereas the diodes operate at the ambient room temperature of 27° C.

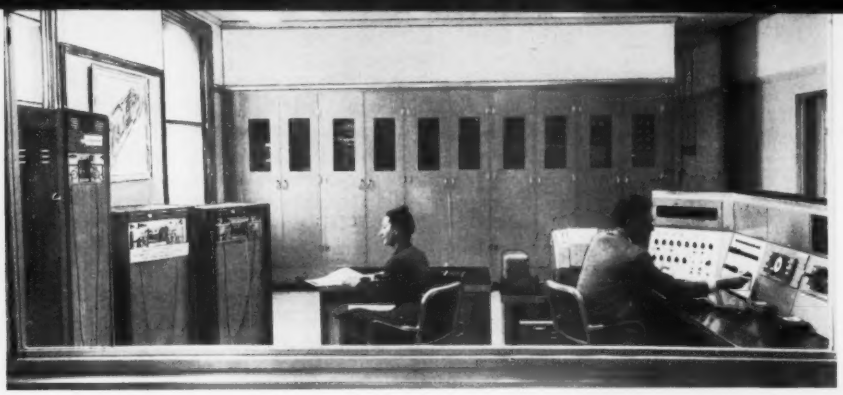
[1] Circuit packages for electronic computers, *NBS Tech. News Bul.* **37**, 36 (*March 1953*).

SEAC Converted to Applications Research Facility

SEAC, the National Bureau of Standards Electronic Automatic Computer, has recently been converted from a scheduled scientific computational facility to a research and development tool for new computer systems and specialized areas of application. Although a nearly round-the-clock schedule of mathematical computation had been maintained for most of SEAC's 7 years of operation, the demand for its services increased to the point where a larger capacity machine was required to carry the workload. With the Bureau's recent acquisition of a commercial high-speed computer, SEAC is now entirely devoted to evaluation studies of components, subsystems, and entirely new kinds of data-processing applications.

Preparation for this role has been underway during the past year. Circuitry for new input-output devices has been installed. High-speed multichannel tape units, perforated paper tape readers, tape perforators, and an alphanumeric printer have been procured and modified appropriately. A scanning device for pictorial input has also been incorporated into the machine. Conversion circuitry for use of an additional mercury memory unit of 512 words has been completed, which makes a total of 2,048 words of memory now available for tryouts of larger-volume data-processing problems. The procurement and installation of an input-output staticizer has made possible direct communication between the SEAC and an analog computer. Use of this equipment, in conjunction with display equipment, permits operation of SEAC and the analog computer as a real-time simulator.

In May 1950, the Bureau announced the completion and successful operation of SEAC by the staff of the data processing systems laboratory. Although it was basically designed as a high-speed computer for scientific problems which inherently have small or moderate input-output requirements, the original system has been augmented sufficiently to undertake data-processing problems of the type that requires a great deal of large-volume data manipulation. SEAC's versatility, as indicated by the many types of problems that it has solved, is in keeping with the original plan of the system as a nucleus to be expanded to meet problem-solving requirements and to test technological advances in the computer field. SEAC has indeed been a proving ground both for new engineering techniques and for



SEAC, the National Bureau of Standards Electronic Automatic Computer. In the foreground, at right, is the main operating console. In cabinets at left are magnetic tape units to store information while problem is in progress. In cabinets at rear is the major portion of SEAC itself. Other accessory units, either in adjacent rooms or moved into this room, can be connected to SEAC to aid mathematicians and scientists to solve specific problems.

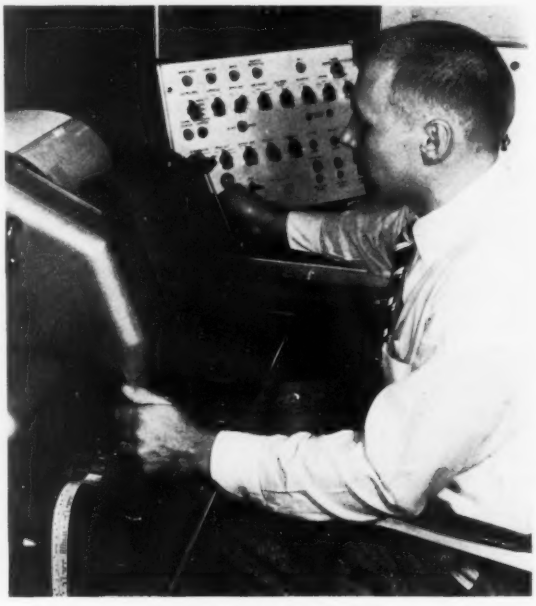
model problems in massive data processing.

SEAC was constructed under the sponsorship of the Office of Air Comptroller, United States Air Force, for research in the application of scientific methods to management. The basic problem was to construct a "mathematical model" of Air Force operations consisting of sets of equations that would describe the relationship of all Air Force activities to the requirements for personnel, supplies, equipment, and facilities of all kinds. With conventional equipment it took months to compute the required program and requirements data. SEAC, capable of adding 4,000 13-decimal-digit numbers per second or performing 400 long divisions per second, paved the way for techniques and equipment that contributed to reducing this time lag so that budget and program could be kept more reasonably current.

SEAC made a major contribution to national defense in performing calculations essential to the development of the H-bomb by the Atomic Energy Commission (AEC). A representative sampling of problems undertaken more recently for the Department of Defense and the AEC includes radiation diffusion, award or procurement contracts by linear programing, integrals involved in supersonic flutter, heat convection, complete degradation in the neutron, reflex klystron efficiency, missile trajectory, dynamic behavior of aircraft structures, and molecular vibration. In addition, problems in meterology, thermodynamics, optics, air-conditioning, numerical analysis, crystal structure, thermal stresses, temperature and compressibility properties of air, and many others, have been solved for the Bureau's technical divisions.

One of the most interesting uses now being proposed for SEAC is to have the machine perform some of the tedious work necessary to the design and development of scientific computers and data processors. Other studies are being undertaken to have SEAC do automatic coding. Although SEAC is probably the oldest general-purpose electronic digital computer in use in the country, it can look forward to several more years of productive use despite its length of service and the expanding state of the art.

Basic to this work on computer systems are research in, and development of, new components, techniques, and improved circuitry. A continuing investigation of semiconductor devices and their properties has led to the development of the diode-capacitor memory, the diode amplifier, and gas diode indicator and display



Control console of SEAC.

devices. At the outset of the fast memory development, the Bureau actively participated for several years in a program of cathode-ray tube improvement for computer storage (memory) application. Research in the utilization of magnetic materials as computer memory elements is in progress, as well as the design of experimental transistor circuitry.

The success of packaged circuitry in the DYSEAC [1] gave impetus to a project to improve the design of the package, reducing its power requirements and size while maintaining its drive ability. This may make possible a computer 100 times as fast as SEAC with a considerable reduction in space requirements. SEAC has been and is continuing to be used to test model designs of such developments as the diode-capacitor memory, an improved Williams memory, diode amplifier applications, packaged circuitry, and other work of the Bureau data-processing-systems laboratories.

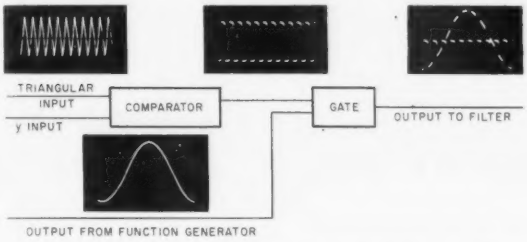
[1] DYSEAC—the new NBS electronic computer, *NBS Tech. News Bul.* **38**, *134 (September 1954)*.

A Function Generator for Two Independent Variables

TO SIMULATE PHYSICAL PROBLEMS on an analog computer, it is often necessary to represent empirical data by functions of several variables. For example, this type of problem occurs in the simulation of aircraft in motion where the parameters of the flight equation are related, in some nonlinear way, to one or more of the variables of motion. Such variables are handled in an analog computer by function generators that provide an output voltage varying in an arbitrary—but controllable—way according to the input voltages.

The Bureau has constructed a function generator that produces an output as a function of two independent input variables. Developed by L. Taback of the analog systems laboratory, the instrument is fully electronic, operates at much higher frequencies than is possible with electromechanical systems, and can be built from commercially available equipment.

Function generators for a single variable are usually based on such electronic devices as tapped potentiometers, *X-Y* plotters operated as followers, and diode-ladders; such mechanical devices as cams; or such

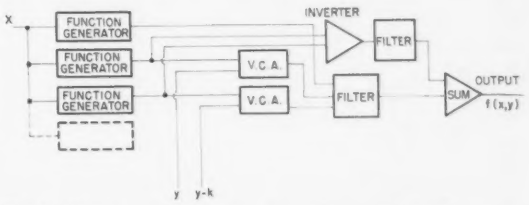


Block diagram of one channel of voltage-controlled attenuator. Whenever the triangular wave plus the *y* input exceeds zero, the comparator turns on a gate to admit the output from one of the function generators. Output of the gate, containing both *x* and *y* values, is filtered to remove the triangular wave.

electromechanical devices as servocontrolled ganged potentiometers. Generators for more than one variable have been devised on extensions of these same principles, but they frequently have shortcomings. Those that are electromechanical are inherently slow and frequently difficult to set up or to modify. Fully electronic devices, while having the requisite speed of response, are generally not completely flexible in the type of functions they may be called upon to generate. To overcome these disadvantages, the Bureau undertook to develop a function generator for two variables that would be fast, flexible, and accurate.

Basically, the Bureau's instrument employs a number of single-variable function generators and provides a method for interpolating linearly between them. The *x* variable drives a number of function generators, whereas the *y* variable drives a number of voltage-controlled attenuators.

Each function generator, except for the first whose



Block diagram of function generator. It produces an output that is a function of two independent input variables.

output corresponds to the value of the function for $y=0$, is fed through an electronic attenuator. Each successive attenuator is adjusted to begin conducting when the previous one is almost fully on. All of the generators are fed in parallel from the *x* input. The outputs of the attenuators are filtered and summed in the output amplifier. A portion of the output of each function generator is subtracted from the output through the use of an inverting amplifier. This is to compensate for the residual output of the voltage-controlled attenuators when they are supposed to be off. A filter is used here to make the frequency response of both amplifiers equal.

The voltage-controlled attenuators receive their inputs from the *y* variable. A triangular wave is generated and compared to the *y* input. Whenever the triangular wave plus the *y* input exceeds zero, the comparator turns on a gate to admit the output from one of the function generators. There is a voltage-controlled attenuator for each function generator except for the case where $y=0$. Whenever the triangular wave plus the *y* is less than zero, the gate is turned off. The output of the gate, containing both *x* and *y* values, is filtered to remove the triangular wave. It is then summed with the outputs of the other gates to produce the desired $f(x,y)$. While the system was designed to provide linear interpolation, it is a relatively simple matter to obtain nonlinear interpolation by changing the shape of the triangular wave.

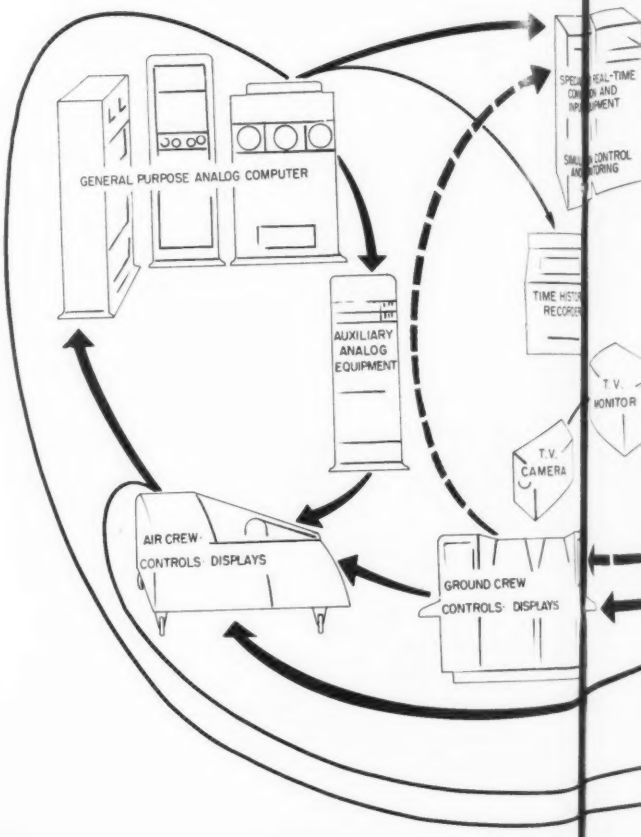
This scheme for the generation of a function of two variables is extremely flexible. The functions can be completely arbitrary, limited only by the frequency capability of the instrument. For the Bureau's unit, operating frequencies up to about 100 cps are acceptable. Linearity of interpolation is about 1 percent, which is generally sufficient for most applications. When used with diode-ladder function generators, the method is conceptually simple and requires no mathematical or graphical work in the setup procedure. Changes in the function are easily and quickly made, and the settings may be recorded so that the function may be reproduced readily at a later date. The system will accept the outputs of whatever type of function generators are available, and the number used may be chosen to meet the requirements of the problem.

Man-Machine Simul

THE BUREAU has designed an advanced research tool that simulates the interactions between electronic control systems and a team of human operators. Containing all the essential elements of a complete simulation facility, a prototype model is being constructed for designing man-machine control systems such as those for air traffic control, ground control of interceptors, and command systems in general. It was developed under the sponsorship of the Wright Air Development Center, with the advice of psychologists from the Aero Medical Laboratory. The mechanical and electronic aspects of the simulator were the responsibility of the Bureau's scientists, H. K. Skramstad, A. A. Ernst, and J. P. Nigro.

One of the research scientist's most potent tools is the mathematical model, which merely simulates the real physical situation and yet enables him to investigate in detail particular phases of his problem. By manipulating this model, either on paper or with the aid of a high-speed electronic computer, he can design complicated systems with more assurance that they will operate satisfactorily when built. A model may be purely mathematical or, as in this instance, may include a considerable array of complicated physical equipment. Such a simulator is now recognized as an essential tool for the development of complex automatic systems. The only alternative to simulation is to build the proposed system and then carry out an extensive testing and modification program, frequently a prohibitively expensive and time-consuming process. The Bureau's effort has been directed toward extending the application of such a tool for research on semiautomatic man-machine systems. The prototype will be used to establish the feasibility and estimate the cost of a simulator which would permit dynamic as well as operational analysis of a projected system, and enable prediction and optimization of the final system in the laboratory.

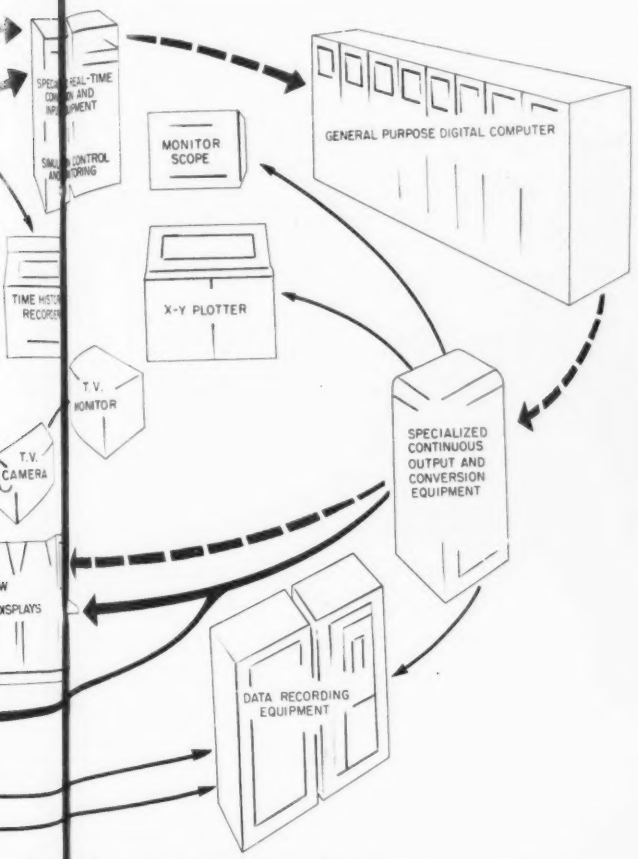
The Bureau's prototype includes a digital computer and an analog computer, linked with display and control equipment which permits human beings to be coupled into the system. This system provides an estimate of how their alertness, judgment, and dexterity will affect otherwise automatic operations. At the same time, it can assess the reasonableness of the tasks assigned to the people in relation to their ability to perform them. Construction of the system is intended to serve three purposes. The first is to deal with the technical and economic factors which could neither be properly anticipated nor adequately resolved by a "paper" study alone. The second is to achieve a better basis on which to specify the facility and to estimate the costs of constructing, operating, maintaining, and expanding it. The third is to test its utility by applying the prototype to the resolution of one or more of the important issues being faced in the current development of control systems.



Block diagram of information flow in the se machine simulation experiments.

Cathode-ray tube display console that simulates a ground control center. The two operators are serving as part of a control loop in the experiments to simulate complex man-machine control systems.

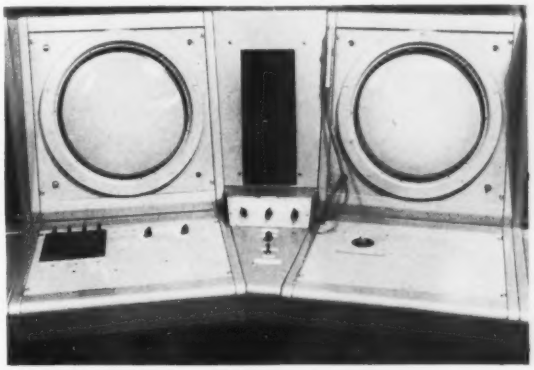
e Simulation System



on flow in the separate elements in the man-ents.

A simulator for man-machine systems differs in several distinct characteristics from one designed for purely automatic systems. It must operate in real time, must have appropriate data presentation for the human operators, and must provide for acceptance of human responses so that the human operator may perform in the simulator in a manner comparable to his performance in the system being simulated. Exact repeatability of results is not to be expected, and much use must be made of statistical methods in analyzing experimental results. Because of equipment limitations, it is often necessary to partition off a portion of the system for simulation. Since a human operator is extremely nonlinear, the superposition process does not apply. Hence, care must be taken that the simulation include features of the human environment that are not directly a part of the control loop under study, but which may possibly affect the loop significantly.

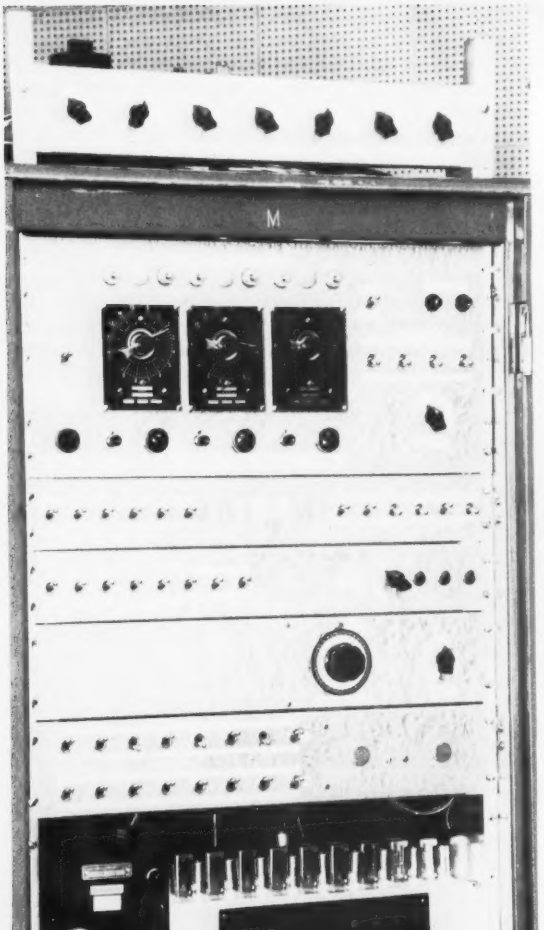
The present equipment is particularly suited to the simulation of sampled-data systems. A combination of analog and digital computer equipment, together with appropriate input-output and conversion devices, was chosen for maximum flexibility, economy, and convenience of operation. Analog computer equipment was used for those tasks which can be handled best by analog computers, such as accepting continuous control information solving complex dynamic equations in real time, and activating conventional display devices. The digital computer was used for tasks that can best be handled by digital computers, such as controlling the experiment, generating open loop data, calculating with high precision, handling variables requiring large dynamic range, making logical decisions, and statistically analyzing experimental results.



Front view of ground control console.

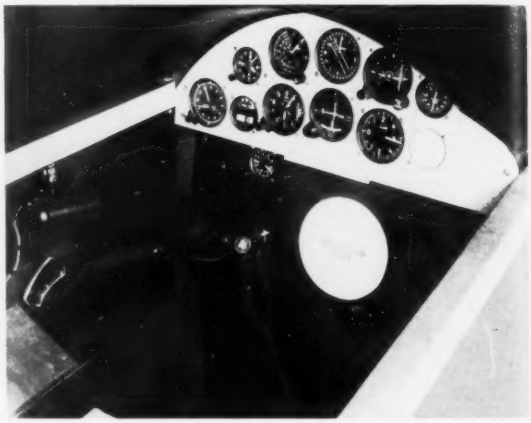
As an example of a high-performance sampled-data system involving human operators as components in a control loop, the ground-controlled interceptor problem was chosen for the first experiments. The facility could be adapted equally well to many other systems of interest, such as air traffic control, ground-controlled approach or landing, weapon assignment, or missile guidance. In the laboratory the real situation of the ground-controlled interceptor is simplified for the purpose of study. The digital computer is programed to simulate the situation where a large number of aircraft are observed by search radar. A console including CRT displays simulates the ground control station. Here, aircraft are manually assigned and automatically tracked. A model of an airplane cockpit enables a human operator to imitate the actions of an interceptor pilot in flight. A control panel operated by the research team permits modification of the hypothetical situation under study.

A general-purpose electronic analog computer simulates the dynamics of the aircraft in real time and activates the flight instruments in the cockpit directly or through special-purpose analog equipment. The velocity components of the interceptor aircraft are converted



Control panel where those conducting a man-machine simulation experiment can alter experimental conditions.

to a ground reference system and integrated over one scanning period of the radar. These increments in position are then sent through specialized real-time conversion and input equipment to a general-purpose digital computer (SEAC). SEAC stores the position of the controlled interceptor aircraft in its memory and updates the information each sampling period of the system. The digital computer also controls the experiment, generates the trajectories of preprogramed aircraft, and simulates the interceptor control computer. The output of SEAC is connected to specialized continuous output and conversion equipment that activates the display equipment for the ground crew, operates a monitor scope, and sends data to an X-Y plotter on both a selected enemy target and an assigned interceptor. Navigation commands from the ground crew are sent to the air crew by voice or by a simulated data link which activates navigation instruments. The airplane controls operated by the pilot are signaled to the analog computer, thus closing the loop.



Interior view of laboratory model of interceptor cockpit.

Any facility intended for research on man-machine systems will produce large quantities of experimental data. In order to draw conclusions from experiments as rapidly as possible, some of the experimental data must be reduced either during or between runs. Reduction between runs may be the more important, since combined simulation and data reduction might frequently make computation demands beyond the capability of the digital computer. Also, the recording of data is desirable for analysis and comparison with subsequent experiments. Magnetic tape is used as the storage medium for experimental data, in information blocks of 16 quantities at a recording frequency variable from one-half to 32 samples per second. The format is such that the tapes may be read into SEAC directly for further processing.

One advantage of this facility is the ease with which the psychologist or engineer can modify his experiment rapidly and conveniently at the control panel. This flexibility avoids the need for frequent reprograming of the digital computer with the attendant delays. The experimenter does not have to be greatly concerned with programing difficulties, since changes are made by turning knobs or throwing switches on the control panel to modify the computer instructions, change system parameters, and control the selection of program subroutines.

Problem Solving on the High-Speed Computer

LARGE scale digital computers are helping the Bureau carry out its fundamental program of research on properties of matter and methods of measurement with increasing speed, efficiency, and thoroughness. As knowledge of the computer's capabilities becomes more widespread, its use is being extended to more and more of the Bureau's work—from basic calibration services to complex studies of nuclear properties.

Moreover, the growing indispensability of high-speed computers, both to management and to scientific and engineering research generally, is clearly shown by the variety, extent, and importance of the problems that have been solved on the Bureau's computers. These problems come from every major field of physical science and technology, from statistical analysis, and from Government and business administration.

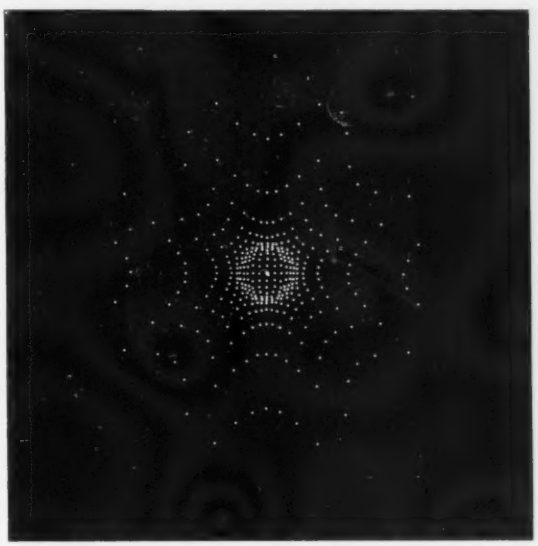
At present, projects are serviced at the rate of about 150 per year, up to the limit of machine time available. Submitted by the Bureau's laboratories and by other Federal agencies, these range from "single-shot" problems, requiring a run of only an hour or two, to comprehensive programs carried out on a continuing basis for several years at a time. From 1950 to 1957 such problems were solved on the Bureau's home-built SEAC; in 1957 an IBM computer, type 704, was acquired. In addition, at the request of other agencies, the computation laboratory programs problems for NORC, UNIVAC, and other machines outside the Bureau.

The problems worked on the Bureau's computers illustrate not only the increasing number of fields in which the potentialities of the digital computer are being exploited, but also the wide range of computational techniques now available. In some cases, as in geometrical optics, the mathematics is essentially elementary. Here the main contribution of the computer is its great speed; but this also permits the inclusion of refinements that lead to better as well as faster results. Solution of systems of ordinary linear differential equations and of many partial differential equations is now almost a routine matter. More sophisticated procedures are found, for example, in studies of radiation penetration which apply Monte Carlo techniques and methods for solving integral equations; in calculations of crystal lattice constants, in which the coefficients of 3-dimensional Fourier series are determined; and in evaluating Government contract bids which apply the techniques of linear programing. Still other methods are illustrated in an extensive program for calculating thermodynamic properties of materials and in a statistical study of traffic trends. These and other problems, selected from those solved or now being calculated at the Bureau, are discussed further below.

Geometrical Optics

Essentially the only way to design a lens system of the kind found in an aerial camera or telescope is by ray tracing. This consists in selecting a number of light rays emanating from some object point, determining by elementary geometry the path of these rays through the lenses, and finding their intersections with the plane of the final image or photographic plate. The deviations of these intersections from the desired image point furnish a measure of the quality of the lens system. The procedure may then be repeated for other object points and possibly for light of other wavelengths. Also, the parameters of the optical system—lens separations, curvatures, and indices of refraction—may be varied to improve the sharpness of the images.

For each choice of parameters, the number of arithmetic operations may run into millions, making use of a high-speed computer mandatory. A computer also has the advantage that it can handle skew rays—those not lying in a plane through the optical axis—as easily as rays that do lie in such a plane; in ray tracing by hand, skew rays are usually avoided as too difficult. As a result, the solutions provided by the digital computer are more thorough and accurate.



"Image" of a point source of light as determined by automatic plotting of the output of a digital computer. Each dot represents the intersection with the image plane of a ray from the object point as refracted by a lens. Scale of diagram is roughly 100 times larger than actual image size.

The principal application of automatic computers to such problems at the Bureau has been to compare the images formed by series of proposed lens designs in order to select the one best suited to a particular purpose. The computer output is automatically converted to graphical form, thus showing directly the appearance of images of point sources.

Thermodynamics, Statistical Mechanics

For the past 7 years, the computation and thermodynamics laboratories have been engaged jointly in the development of high-speed computer techniques for calculating thermal properties of materials. Needs of research on propulsion systems provided the original stimulus for this project, but the computed data have a far wider range of application. Thus far most of the work has dealt with gases, and the results are in the form of tables of various thermodynamic and transport properaties over a range of pressures and temperatures. Among the properties included are specific heat, entropy, heat content, vapor pressure, sound velocity, viscosity, and Prandtl number. With the aid of such tables it is possible, for example, to calculate the amounts of heat generated or other details on the course of chemical reactions inside a combustion chamber and the thrust of the resulting jet.

Since they form the starting point for many other calculations, the ideal-gas thermodynamic functions (for atoms, atomic ions, molecules, molecular ions, and radicals) were the first to be programed. Programs were then developed for calculating (1) equations of state based on a virial representation of data of state, (2) gas-imperfection corrections to the thermodynamic properties for compounds and mixtures of fixed composition, and (3) equilibrium compositions and properties for chemically reacting gaseous systems.[1]

One phase of the work is summed up in NBS Circular 564, which contains data for air, argon, carbon dioxide, hydrogen, nitrogen, oxygen, and steam.[2] Plans are being considered for applying the same techniques to a systematic calculation of thermal properties for all atoms and their ions at temperatures up to 1,000,000° K.

Satellite Calculations

Working in cooperation with the Naval Research Laboratory, the Bureau is engaged in programing and computing for a number of satellite problems. The most important of these relates to the determination of upper atmosphere properties. Thus, by combining recent high-altitude rocket measurements with observations of the rate of change of period for the first Russian satellite (Alpha 2), it was possible to obtain reasonably good values for the atmospheric density at altitudes up to 400 km. At 200 km the results agree well with typical earlier estimates, but at 400 km a density 40 times greater was found. One consequence of this finding is to reduce estimates of satellite lifetime by the same factor for orbits with a perigee (i. e., minimum) altitude near 400 km. Other projects deal more directly with satellite lifetime and with the satellite's final dying period and point of impact. A theoretical investigation on the "interpretation and ambiguity resolution" of Minitrack observations is also underway.

In still another project, the computation laboratory has prepared a program for an approximate satellite ephemeris (or table of positions), using the basic equations provided by NRL. The program is designed for rapid calculation of the position of the satellite in a form convenient for use by Minitrack stations and tracking radars. The program first integrates the equations of motion, with atmospheric drag included, and then transforms the satellite position to spherical coordinates fixed in the earth. In accordance with the aim of providing a quick, approximate table of positions, the precession of the orbit plane and the rotation of the line of apsides are included in a phenomenological form in the second part of the program. The printed output gives the latitude and longitude of the satellite, as well as its position relative to a number of observing stations, at intervals of 1 minute. The printout may be restricted to any specified range in latitude and longitude.

Radiation Penetration

Computations on radiation penetration form one of the very large computer projects at the Bureau. The results are directly useful in fundamental physical research, radiology, reactor design, and evaluation of effects of nuclear weapons.

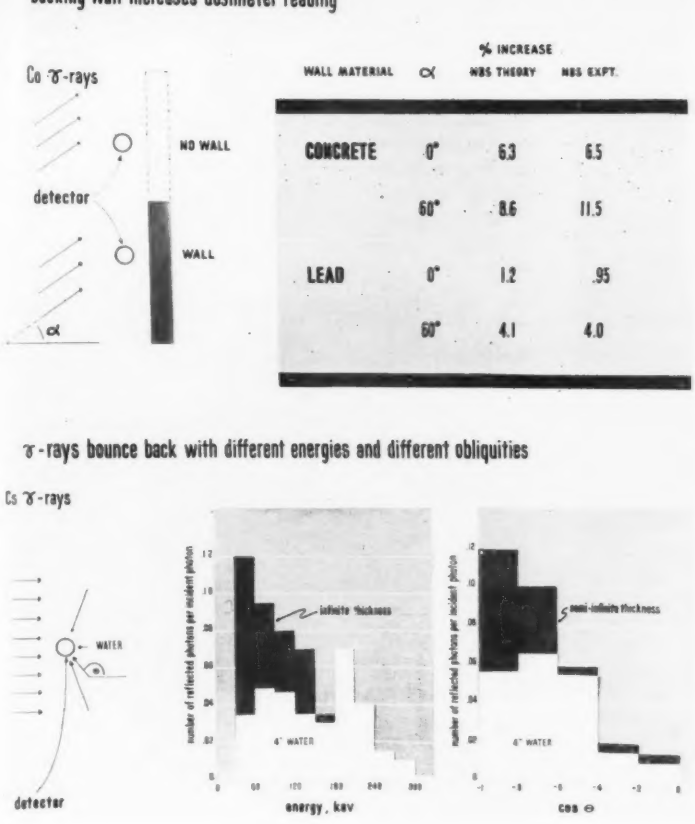
The problem is to find out what happens to a beam of radiation when it traverses bulk matter. The particles in the beam—gamma-ray photons, electrons, neutrons, or others—collide with atoms of the matter and then are absorbed or scattered into different directions, often with ejection of particles or photons from the atoms; scattered and ejected particles can then enter into further collisions. The specific problem is to determine the number of particles at a given depth of penetration and moving in a given direction with a given energy.

There are two main approaches to this problem. The Bureau's nuclear physics laboratory has made contributions to each method.[3] In the first, the desired distribution is expanded into series with respect to 2 of the 3 independent variables, and the coefficients are found to satisfy certain linear integral equations. These are approxmated by systems of linear algebraic equations that prove to be of a type that can be solved recursively. The other method is an application of the Monte Carlo technique, which consists in setting up a numerical analog to the situation under study.

Crystal Structure

When a beam of X-rays impinges on the regular array of atoms in a single crystal the rays are diffracted to form a pattern of isolated spots as detected, for example, on a sensitive screen. Information about the crystal structure is obtained from the positions and intensities of these spots. However, except in the simplest cases, this cannot be done without extensive calculations. To supply the information needed by chemists, crystallographers, and solid-state physicists, a computer must be used.

The procedure is based on the relation that exists between the diffraction pattern and the density distribution of the electrons that surround the atoms in the



Diffuse reflection of gamma rays, illustrating results of Monte Carlo calculations made with high-speed digital computer. Table above gives data for two different angles of incidence. *Below:* Results on reflection of 0.66-Mev gamma rays by water barriers of different thicknesses. Graphs show distribution in energy and direction.

crystal. When the electron density distribution is expressed as a 3-dimensional Fourier series, each coefficient (called a "structure factor") in the expansion is a complex number that represents the intensity and phase of an individual spot in the diffraction pattern. Since only the intensities of the spots can be measured, additional assumptions based on chemical experience must be made. The computing methods enable any such assumption to be tested, and various devices have been developed to avoid excessive trial-and-error steps. At the same time, the computer is being used to evaluate newer methods that dispense with conjectures based on chemical experience; such methods would be highly impractical without the use of high-speed computers. The computer is also used to refine the results of previous calculations by determining the corrections required by improved experimental data.

When a crystal is ground into powder, the diffraction pattern becomes a series of concentric rings. From the location and intensities of these rings it is possible to identify the chemical composition of the crystal, and this technique is now widely used in industry. The ring pattern is related to the spacings between planes in the various systems of parallel planes that pass through atoms in a single crystal. Such spacings, called "*d*-values", are computed from results on single crystals and serve as indices for identifying different materials. This computation is then done in reverse, using *d*-values obtained from Bureau laboratory measurements to correct the structure constants.[1]

Procurement Bid Evaluation

The analysis of bids to determine the "low bidder" among potential contractors is more involved than first appears. In the case of Government procurement bids there are an average of 20 bidders, each of whom may have different sliding scales relating prices and quantities, may quote different prices for work done at different plants, may set minimum or maximum quantities, may be able to supply goods only to certain Government depots, or may accept an award only if he also receives—or does not receive—the award on some other bid. Also to be considered are the requirements of the various Government supply depots and the transportation costs from each potential plant to

each depot. Additional complications enter when the Government furnishes raw materials, for example, textiles for uniforms.

Methods for applying computers to this task have been developed by the Bureau for the Department of Defense over the past several years.[5] The basic problem is of the type known as a "transportation problem" which, in turn, is one kind of problem in linear programming. The Bureau's methods are based on the simplex method of G. Dantzig as modified for the transportation problem. With experience in its use, the technique has been made more versatile, so that many of the complicating factors can be taken into account in a single run of the computer (requiring only a few minutes). Previously, separate runs were needed for each complicating factor over and above the basic transportation problem pattern.

Traffic Trends

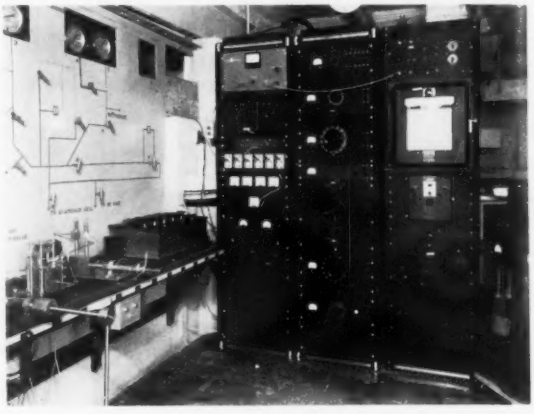
A somewhat different type of problem arising in Government administration is illustrated by a project recently completed for the Bureau of Public Roads. This problem involved the relative accuracy of 4 proposed methods for predicting changes in traffic patterns. Accurate anticipation of trends in traffic distribution would clearly help in planning more effective road and highway networks. The computer was used for calculating predictions by the various methods and for comparing the results with data obtained by a home-interview sampling technique in the Washington (D. C.) metropolitan area in 1948 and 1955. It was estimated at the outset that 25 million unit computations would be required; on the very optimistic allowance of 10 seconds per computation, this would require about 35 man-years for completion by hand methods. The actual computer time was 30 hours, which includes additional computations not considered in the original estimate.

Mathematical Tables

The development of the high-speed computer has not made the use of mathematical tables obsolete, but it has changed some of the characteristics that are expected of them. For use in computer operations, "skeleton" tables are useful, giving values to many significant figures and accompanied by auxiliary functions for calculating intermediate values. Tabular material covering only a few pages can thus replace tables that formerly occupied several volumes. Moreover, those without access to a large scale computer still need tables of the elementary functions and an increasing number of the higher functions—for example, confluent hypergeometric, spheroidal, and Sievert functions.

To meet these new needs, the Bureau is preparing a *Handbook of Mathematical Tables*[6] which will include graphs and texts material as well as tables. There will be 28 chapters, including tables of mathematical constants, powers and roots, elementary and higher transcendental functions, and basic tables for combinatorial analysis, numerical analysis, and statistics. The text material will give for each function the important mathematical properties that are useful in computational problems. With considerable help from the Bureau's computer, the preparation of the volume is now well advanced.

The *Handbook* is sponsored by the National Science Foundation, and its contents are being determined by Bureau staff members with the assistance of a Committee on Revision of Mathematical Tables appointed by the National Research Council. The primary aim is to include a maximum of useful information within the limits of a moderately large volume (about 1,000 pages), with attention to the needs of scientists in all fields.



Apparatus for measurement and control of temperature and pressure for experimental equation-of-state determinations. These determinations provide part of the input data in the electronic computer program for calculating thermodynamic properties of materials.

Programing Techniques

Before a problem can be set into a computer, it must be programed, a task which is performed by the Bureau's computation laboratory or by personnel of the originating section or agency. Programing for a new problem may require anywhere from a few hours to several months; then the machine may do its work in minutes or it may take hundreds of hours. When later a similar problem is submitted, the old program can often be adapted to the new data without much delay. It is thus important to accumulate a library of program routines and subroutines that may be assembled like standard parts to fit as wide a range of problems as possible. In addition, the possibility of using the computer itself in working out programs is being actively studied and promising results have already been obtained.

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[5] Mechanized computation of thermodynamic tables at the National Bureau of Standards, *by J. Hilsenrath and J. H. Wegstein, in Proceedings of Conference on Thermodynamic and Transport Properties of Fluids, The Institution of Mechanical Engineers, London, July 1957 (in press).*

[2] *National Bureau of Standards Circular 564*, Tables of thermal properties of gases, *by J. Hilsenrath and others, 1955; available at $3.75 per copy from Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.*

[3] *A descriptive summary is given in* Penetration and diffusion of gamma rays, *NBS Tech. News Bul.* **40**, *144 (Oct. 1956). For further technical details see, for example,* Penetration of X- and gamma-rays to extremely great depths, *by U. Fano, J. Research NBS* **51**, *95 (1953) RP2439*; Penetration and diffusion of X-rays: calculation of spatial distribution by polynomial expansion, *by L. V. Spencer and U. Fano, J. Research NBS* **46**, *446 (1951) RP2213*; Reflection and transmission of gamma radiation by barriers: semianalytic Monte Carlo calculations, *by M. J. Berger and J. Doggett, J. Research NBS* **56**, *89 (1956) RP2653.*

[4] X-ray diffraction patterns for identification of inorganic solids, *NBS, Tech. News Bul.* **37**, *189 (1953). Results on crystal powders are published as National Bureau of Standards Circular 539,* Standard X-ray diffraction powder patterns, *by H. E. Swanson and others. Volumes I to VII have appeared (1953–1957) thus far; they are available from Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. at 45¢ per copy for volumes I–V and 40¢ per copy for volumes VI and VII.*

[5] SEAC determines low bidder, *NBS Tech. News Bul.* **38**, *179 (1954). For further technical details, see* Experiences with the bid evaluation problem, *by H. Bremer, W. Hall, and M. Paulsen, Naval Research Logistics Quarterly* **4**, *27 (1957)*; Linear programming in bid evaluation, *by E. D. Stanley, D. P. Honig, and L. Gainen, Naval Research Logistics Quarterly* **1**, *48 (1954).*

[6] Handbook of mathematical tables, *NBS Tech. News Bul.* **41**, *94 (June 1957).*

Measuring X-ray diffraction patterns of powdered crystals with diffractometer. Measurements are used in high-speed computer calculations of crystal structure constants (*d*-values) which, in turn, are used in industry for identifying crystalline materials.

Chemical Structure Searching With Automatic Computers

THE BUREAU and the United States Patent Office have been actively collaborating on a long-range program to develop and apply automatic techniques of information storage and retrieval to problems of patent search. In experiments carried out by L. C. Ray and R. A. Kirsch of the Bureau's data processing systems laboratory, a collection of over 200 descriptions of steroid chemical compounds was exhaustively searched with a high-speed electronic computer to answer typical questions that might occur in evaluating a patent application.[1] The methods developed can be applied with little or no modification in examining descriptions of most chemical compounds.

In the granting of United States patents, it is necessary for patent examiners to refer to literature collections that contain from 1,000,000 to 10,000,000 documents. Before granting the patent, the examiner must assure himself that he has exhaustively searched through all documents in the public domain that might contain information pertinent to the given application. An estimated 60 percent of the time spent by an examiner in processing a patent application is thus devoted to searching the technical literature. In an attempt to reduce this time, the National Bureau of Standards—Patent Office group has considered, among other techniques, the use of automatic data processing systems.

An automatic data processing system (ADPS) is a collection of equipment machines, usually electronic in nature. The system can process information in accordance with internally stored programs and can perform a whole data processing task involving the use of extensive data storage facilities without manual intervention. It also includes devices for the preparation of input data and the reproduction of output data. SEAC, the National Bureau of Standards Electronic Automatic Computer, is an ADPS and has been used in successful preliminary experiments in patent search techniques.

The area that was selected for initial experimental investigation was that of "Composition of Matter", i. e., patents generally concerned with what may loosely be classified as chemistry. Chemists have, for a long time, been concerned with information retrieval, and it was hoped that use could be made of some of the techniques that chemists had developed. As it turned out, successful results were obtained by taking advantage of a technique of chemistry that was probably not originally developed for information retrieval: namely, the use of chemical structural diagrams for describing the chemical nature of matter.

In using automatic techniques for the retrieval of technical information, no more information can be obtained from a file than is represented according to a well-defined consistent notational scheme. Because the method of representing chemical structures in diagram-

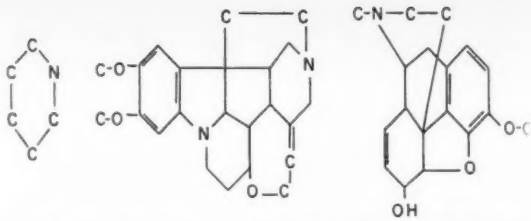
matic form has just such properties, the Bureau decided to experiment with the use of SEAC for searching through files of chemical structure diagrams.

In the Patent Office, the examiners in the chemical arts have frequent need to perform so-called generic searches through structure diagrams. As an example, in examining the compounds brucine and codeine, two similar rings are found even though the diagram of codeine contains the ring in a distorted manner. The two compounds are therefore said to share the generic property of containing this fragment. Part of the experiments performed on SEAC were concerned with developing a method for performing generic searches of this type through a file of steroid chemistry structures.

In the system used on SEAC, each atom in a structural diagram is numbered serially in arbitrary order. One unit of computer storage, called a word, is given to each atom to represent its position in the structure. In each word are listed the numbers of the other atoms, up to four, that are attached to the atom represented by the word. The element symbol and the serial number of the atom are also placed in the word. Thus, each coded atom word has six fields: The serial number of the atom, four connection fields, and an element symbol. Once the code is known, the structure can be redrawn. The code for any structure is not unique since by numbering the atoms in some other arbitrary order a different code would be obtained. It can be shown, however, that all of the possible codes are equivalent.

A file of coded structures is searched by machine for all structures that are identical to some question compound or which have some generic property in the sense previously defined. The SEAC search program tries to make an atom-to-atom match between the atoms of the question structure and the atoms of the first structure recorded in the file. Each match that is made is considered as tentative by the program until the search through the first file structure is completed. Whenever failure to match is discovered by the program, it tries to go back to the previous match to make a new match. If the program finds that all possible first matches lead to irreconcilable mismatches, the program will reject the first file structure and proceed on to the next. When a one-to-one correspondence exists between each of the atoms of the question structure and the atoms of part of the file structure that is being examined, the routine accepts the structure by printing on the computer output an indication of the structure that was found. The search routine continues this process until the whole file has been searched.

Even with a high-speed electronic computer, such a detailed search can be very time consuming. Shortcuts must therefore be devised to speed up the process without compromising the exhaustiveness or accuracy of the search. Techniques are needed that will enable the ADPS to perform a cursory inspection of a small piece of data in such a manner that most structures not satisfying the search requirement will be rejected immediately. Such a technique is called a "screen" or "screening device". It is essential that a screening device should never reject a structure when that structure does in fact meet the search requirement. The screen is



The Bureau has developed techniques for electronic computers to make generic searches through chemical structure diagrams. As an example, the ring shown at the left is contained in both the brucine (center) and codeine (right) structures. The two compounds share the generic property of containing this fragment. A high-speed electronic computer can discover this or any other fragment common to a number of compounds.

acceptable, however, if it allows some structures to be considered further by the structure search routine even though they are subsequently rejected as failing to meet the requirements.

One such useful screen is inherent in the empirical formula of a chemical structure. Stored in the file, along with the description of the chemical structure, would be a list of the number of occurrences of each type of atom in the structure. The ADPS can inspect this list before it searches the structure to find out whether there are enough atoms of the right type present to satisfy the search requirement. Such a screen has been incorporated into the SEAC search program; on most searches it enabled the computer to reject quickly the vast majority of structures that would otherwise have been the subject of a long computational procedure.

The SEAC experiments indicate the practicality of using an ADPS for very rapid scanning of a file. However, many mechanisms considerably simpler than an ADPS could also do such scanning, and the question remains as to the comparative advantages of an ADPS and the simpler mechanisms for the actual process of looking at a properly organized file. In some retrieval situations, most notably in the Patent Office, the problem is of sufficient magnitude and complexity that the power of an ADPS to do more than just scan a file appears to be a requirement. The ADPS seems to offer a unique contribution in the auxiliary operations. For such functions as preparing a search prescription, editing a file, eliminating errors, transliterating from one code to another, exploring complex logical conditions imposed on the question and file structures, and probably many others, the ADPS offers the outstanding virtues of high speed and great versatility. SEAC cannot only be used to test the utility of an ADPS for the Patent Office retrieval problem but also to study the performance of other devices by simulating them. In the computing machine field it is well-known that machine users discover many new applications of these machines while in the process of using them. It is expected that further experiments on SEAC will serve a similar purpose.

[1] *For further technical information, see* Finding chemical records by digital computers *by L. C. Ray and R. A. Kirsch, Science* **126**, *814–819 (1957).*

Magnetic Amplifiers for Digital Computers

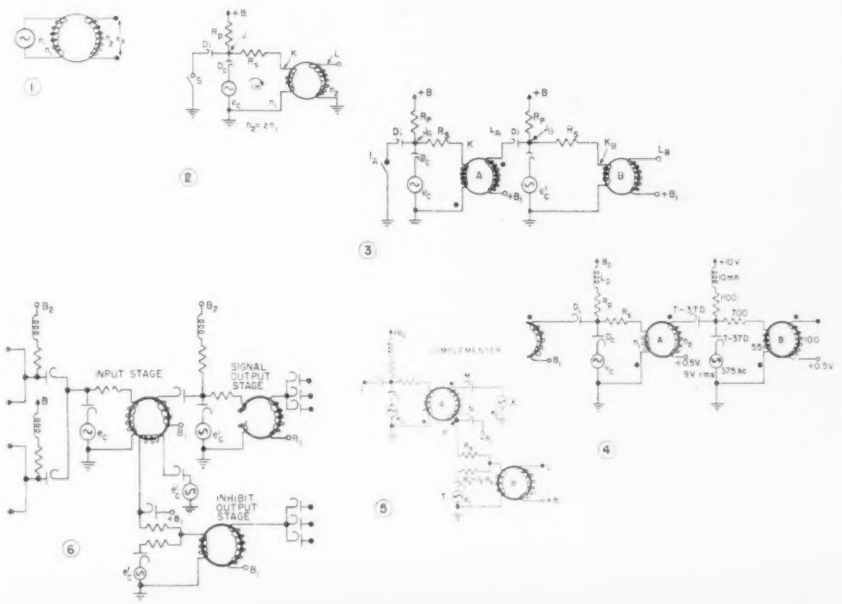
THE BUREAU has been investigating digital amplifiers of noncritical design based on saturable voltage transformers.[1] Results indicate that these amplifier stages are particularly suited for use with diode gating to provide the "and", "or", and "not" logical functions required by digital computers. As part of a program sponsored by the United States Air Force Cambridge Research Center, the investigation has been carried out by E. W. Hogue of the Bureau's data processing systems laboratory.

Semiconductor diode gating is one of the most satisfactory ways to realize the logical functions of a high-speed digital computer. This type of gating is economical in components, straightforward in concept, flexible, and dependable. However, because signal power is lost in transmission through the gates, it is necessary to insert amplifiers at intervals within the gating structure to regenerate the signal. Such amplifiers must fulfill four conditions: (1) They must be compatible with diode gating; (2) they must have power gain; (3) there must be no possibility of reverse transmission of signal; and (4) they must have a transfer characteristic that will ensure stable circulation of binary signals in closed logical loops or in long cascades. Vacuum tubes and transistors have been used successfully for amplifiers that meet these conditions. However, because saturable transformers seemed to offer good possibilities for compactness, dependability, and low-power consumption, the Bureau undertook to investigate these components for application to digital computer circuitry.

Amplifier Circuit

The amplifier consists essentially of a transformer having a toroidal core of rectangular loop material, driven by an a-c source. This basic circuit is shown in figure 1. The power source has an amplitude e_i and a wave form approximating either a square or sine wave. The convention is adopted that the positive half-cycle of e_i puts the core in the binary "one" state. During this positive half-cycle of e_i, the core is said to "receive" information. The negative half-wave returns the core to its binary "zero" state. At this time the core "transmits" the signal it has previously received. The voltage e_o appearing across the output winding during the transmit half-cycle is the output signal of the transformer. The voltage appearing across this same winding during the receiving half-cycle of e_i has no significance, and has negligible effect on the following stage.

To make possible the introduction of ones or zeros into the amplifier, a resistance-diode network is added to the input of the amplifier as in figure 2. The source e_i is replaced by the combination of (1) R_p, a pull-up resistor connected to a positive voltage $+B$ to provide a constant current pull-up; (2) semiconductor diode D_c, the clock diode; (3) e_c, an alternating voltage source or clock signal; and (4) D_i, the input diode. A switch S provides for the manual introduction of ones or zeros to the stage. R_p is large compared with the input impedence to ground from point J, and $+B$ is made large enough to provide a constant current suf-



Development of digital amplifier of simple noncritical design using saturable-core transformer. Figure 1 shows simple pulse repeater; figure 2 has diode switching in input; figure 3 is two-stage pulse repeater; figure 4 is further improvement over figure 3; figure 5 shows complementer; figure 6 is proposed complete pulse repeater stage with both positive and negative outputs.

ficiently greater than i_m to keep D_c conducting, even on the most positive excursion of the clock.

When the switch S is open, the stage transmits ones. When S is closed, it transmits zeros. The condition required for the stage to transmit ones is that the impedance to ground looking to the left from the point J be high during the receiving half-cycle. The condition required for the stage to transmit zeros is that this impedance be low during the receiving half-cycle. During the transmission half-cycle this impedance must always be high. This condition is ensured by the polarity of the input diode D_i.

Two magnetic binary repeater stages can be connected in cascade as in figure 3. Note that the two clock voltages, e_c and e'_c, are 180° out of phase. Binary signals are introduced into stage A with the switch and transmitted to stage B, which in turn repeats them at its output L_B. The small positive bias B_1 has been added to the circuit. The polarity of B_1 is opposite to the input diode D_i and its amplitude is about one-tenth the peak clock voltage. The transformer introduces a polarity reversal of the signal as shown by the dots. Operation is similar to that of the single stage.

Further improvement of the repeater stage (fig. 4) is achieved by adding a high-reactance (at clock frequency) choke in the constant-current pull-up branch. The choke L_p permits low values of B_2 and R_p, greatly reducing the waste of d-c power in R_p. Total maximum d-c and a-c power consumed in the stage is approximately 0.27 watt.

Complementer

Since a computer requires a logical "not" function, a complementer was developed as shown in figure 5. It requires two stages. In this circuit, stage B is continually provided with a transmit pulse by clock Y through R'_s, but its receive or reset pulse must come from point P. When stage A transmits zeros, its output winding is very nearly a short circuit. Therefore, on its positive excursion, clock X carries P along with it because of the low impedance of the output winding and diode M. Diode N is open during this interval. Current from X resets core B through series resistor R_s. Negligible current passes through R'_s because of the positive excursion of clock Y which is in phase with X. On the negative or transmit half cycle for core B, diode N clamps P at the level $+B_1$, and M opens. In this way a reset pulse is provided for B when A transmits zeros, and consequently B transmits ones. Conversely, when A transmits ones, it generates an end which opposes that of clock X. During this time, as a result of the positive bias given to the winding by $+B_1$, diode M remains open, and P remains clamped at the $+B_1$ level. Therefore, because no reset pulse is available to core B, it transmits zeros. The cores in both stages operate under the same conditions and in the same manner as in the simple repeater stage.

Magnetic Amplifier Package

Figure 6 shows a proposed magnetic repeater that makes use of cascading for increased amplifying power and incorporates a complementer for inhibiting. This complete logical package consists of portions of and-gates followed by an or-gate, and an input repeater stage followed by two output stages in cascade. The upper output stage provides an amplified signal output. The lower output stage provides an amplified inhibit output. The and-gate diodes are directly associated with the outputs of the package rather than with the inputs. This places the capacitive load of the leads between packages on the anode side of the input diodes rather than on the cathode side. During the transmission of ones, the impedance from the cathode side to ground is considerably higher than that from the anode side to ground. This arrangement also ensures that the pull-up currents of the driven stages will not be combined in a single long lead. The inductance of such a lead could well exceed the saturation inductance of the stage output winding. There is a delay of one full clock cycle through the package.

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[1] *For further technical details, see* A saturable transformer digital amplifier with diode switching, *by E. W. Hogue, Proceedings of the Eastern Joint Computer Conference (1957) (Held Dec. 10-12, 1956) Special Publication T-92.*

Diode Amplifier Shift Register

THE DIODE AMPLIFIER TECHNIQUE, which uses the reverse transient phenomenon of semiconductors to achieve gain, has been applied to an electronic computer shift register at the Bureau. The shift register, limited in size for convenient laboratory experimentation, consists of a number of flip-flop and counting circuits based on the diode amplifier. Devised by J. A. Cunningham and P. A. Mantek of the data processing systems laboratory, the system embodies many of the operations required for a full-sized computer installation and has operated successfully for several thousand hours.

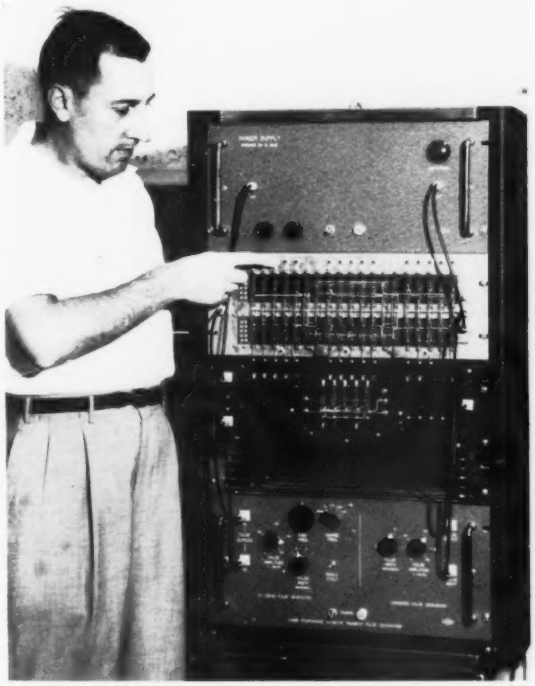
A semiconductor diode is characterized by high conductivity when voltage is applied in the "forward" direction and low conductivity when voltage is applied in the "reverse" direction. The forward voltage helps electrons and holes to diffuse freely across a junction from the region where they are majority carriers into the region where they are minority carriers. The resulting high concentration of carriers throughout the semiconductor provides high conductivity. Reverse voltage, on the other hand, draws the carriers away from the junction toward their own regions, leaving a layer at the junction quite depleted of carriers and, hence, with low conductivity.

If the voltage applied to the diode is switched quickly from forward to reverse voltage, a transient phenomenon occurs. A large reverse current flows through the diode for an appreciable length of time after the reverse voltage has been established, because the minority carriers are swept across the junction and thus augment the static reverse current. Power is gained, and conse-

quently amplification occurs, because charges introduced by a low voltage during forward bias are collected at a much higher voltage during reverse bias.

This amplification is clearly not a continuous phenomenon. However, when an alternating current or a train of pulses is applied to a diode amplifier, the resulting pulsed output is of great usefulness in digital computer switching circuitry. It should be pointed out that the transistor, too, shows the same phenomenon under appropriate circumstances.

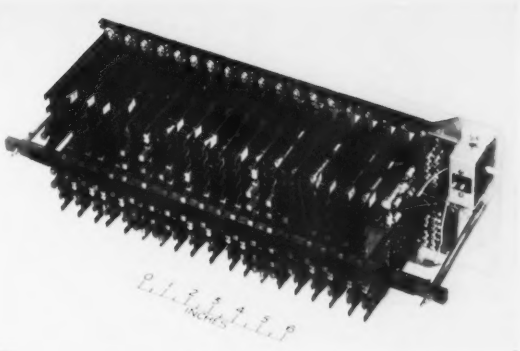
The diode amplifier technique was developed at the Bureau in 1954 and investigated for its possible applications to electronic computer circuitry.[1] A number of basic circuits using the technique were developed at that time, including several types of pulse repeaters and



Diode amplifier shift register. In this rack are contained not only the shift register itself but a ring counter, pulse generators, and a power supply.

a number of different flip-flop circuits. More recent studies have shown how these basic circuits can be successfully combined into more complex computer elements such as a shift register. One thing needed in a shift register is a short memory between successive stages. Several types of diode amplifiers were tried, but the most simple and reliable circuit developed for the short memory employed the minority-carrier storage effect in a transistor.

A transfer pulse applied to the base provides a forward bias to the emitter junction if the preceding flip-flop contains a "1". The minority carriers thus inserted



This assembly contains three complementary five-stage diode amplifier shift registers. The circuitry is contained on 38 printed circuit boards.

into the base are swept into the next stage when the end of the transfer pulse restores reverse bias to the collector junction.

As part of the study, several types of shift registers were designed and preliminary models were constructed and evaluated. In one of the fastest circuits, silicon junction diodes were selected for the delay line type of flip-flop and transistors for the transfer functions. The maximum transfer speed obtained was 3 Mc, using a 10-Mc sine-wave switching voltage.

The development of a method of and-gating that also uses the diode amplifier was added to the flip-flop and the transfer circuit to form a logically complete set of switching-circuit building blocks. The output of the and-gate comes from a diode-amplifier flip-flop that is biased so that it tends to turn itself on. The inputs are other flip-flops coupled to the output flip-flop by diodes or transistors in such a way that if any of them are not turned on they will load the output flip-flop enough to keep it from turning on. For constructing a laboratory system to test these elements they were incorporated into three types of plug-in packages: (1) A flip-flop with a transfer mechanism; (2) a flip-flop with a transfer mechanism having an emitter-follower transistor stage; (3) a flip-flop with transfer mechanism and several and-gate transistors connected to the flip-flop.

The system built up from the packages consists of three five-bit shift registers, a count-down ring counter, and several gating operations. Two of the five-bit registers can shift their information serially in an "end-around" configuration, or exchange their contents by shifting into each other. This end-around or exchange operation is controlled by a bit in the third register. The third register is an end-around register which operates at one-fifth the speed of the first two registers. The ring-of-five counter provides the necessary division. The system has operated without error for several thousand hours. It uses 65 transistors and 43 diode amplifiers, and was constructed with unselected components.

[1] The diode amplifier, *NBS Tech. News Bul.* **38**, *145 (October 1954)*.

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Publications of the National Bureau of Standards

Periodicals

Journal of Research of the National Bureau of Standards, Volume **60**, No. 3, March 1958 (RP2833 to RP2843 incl.) 60 cents. Annual subscription $4.00, $1.25 additional for foreign mailing.

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